Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp692-693

Probing ambipolar carrier injection into pentacene field effect transistors using charge modulation spectroscopy and displacement current measurement

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1. INTRODUCTION

With development of high-performance organic semiconductor materials, fabrication of organic electronic devices such as field-effect transistors (FETs) and light-emitting diodes (LEDs), is attracted considerable interest. However, understanding of the operation mechanism in the OFET is still insufficient. A fundamental research is important to improve the performance of organic devices.

The organic device operation is governed by the injected carriers [1]. Therefore, metal-semiconductor contact particularly dominates the device operation. For instance, ambipolar behavior in OFET was observed by using appropriate electrode metals, i.e. electrons and holes are selectively injected from electrode with small and large work function, respectively. This is a significant feature of the injection type devices. It was also reported that preparation process of metal electrode significantly affects the device properties [2]. Thus, an adequate evaluation and control of injection processes is of great importance to improve the device performance effectively.

Carrier injection has been conventionally studied using electrical measurement such as the displacement current measurements. On the other hand, the spectroscopic technique also provides us significant information of carrier behavior from microscopic point of view. For instance, injected holes reduce electron population of the HOMO level, and results in the attenuation of the HOMO-LUMO absorption of materials. In other words, formation of the anionic or cationic state of molecule due to carrier injection reduces the original optical absorption of the neutral molecule. Accordingly, charge modulation spectroscopy (CMS) has been proposed to observe the carrier behavior [3]. In this presentation, microscopic CMS measurement was conducted in combination with the displacement current measurements to probe the ambipolar carrier injection into pentacene FET.

2. EXPERIMENT

Samples used here were top-contact pentacene FET (channel length was 60 μm). Thickness of the insulating layer (SiO_2) and pentacene were 500 nm and 100 nm, respectively. To observe the ambipolar operation, 100 nm thick poly(methyl methacrylate) (PMMA) layer was spin-coated before the pentacene deposition. Figure 1 illustrates the optical setup for the present experiments. White light with a spot size of 10 μm was incident to the sample, and the reflected signal was analyzed using a polychromator and a high sensitivity cooled charge coupled device (CCD) image sensor. External voltages were applied using source meters (Keithley: 2400) to observe the charge modulation

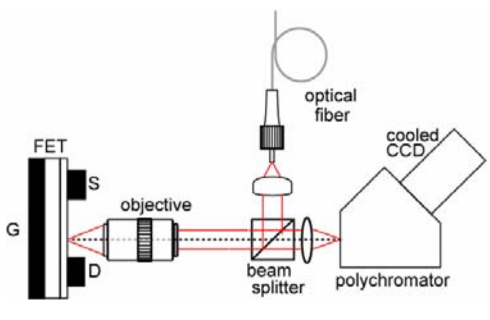

Fig.1 Optical setup for the microscopic CMS measurement and

of the optical signal. For the DCM experiments, a triangular wave voltage was applied to the devices using a high-speed voltage amplifier and a function generator, and the current flowing through the closed circuit was measured. Amplitude and scan rate of the triangle bias were 140 V and 5.6 V/s, respectively. All measurements were performed in vacuum.

3. RESULTS AND DISCUSSIONS

Before the CMS measurements, characteristics of carrier injection were confirmed by the displacement current measurement [1,4]. Figure 2 shows the results of the displacement current measurement for the top-contact pentacene FET in vacuum. As shown in the figure, holes are smoothly injected under the negative gate voltage, indicating low threshold voltage of hole injection. On the other hand, electron injection was also clearly observed with an injection threshold of 60 V. In spite of using Au electrode, ambipolar characteristic was clearly observed.

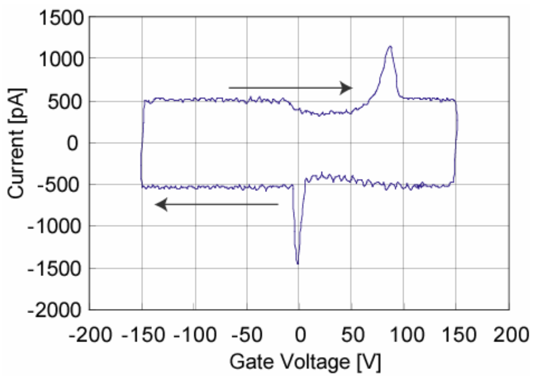

Figure 2 Displacement current observed by appliing ramp voltage to the FET. Arrows represemt voltage sweep direction.

Figure 3 shows the charge modulated microscopic reflectance spectrum obtained under the application of negative and positive gate voltage. To obtain the modulated spectrum, the off-state (Vg= Vd = 0 V) spectrum was subtracted from the reflectance spectrum under the gate application. As shown in the figure, signal modulation was clearly observed under the negative and positive gate bias application, where holes and electrons are respetively injected and accumulated at pentacene/PMMA interface.

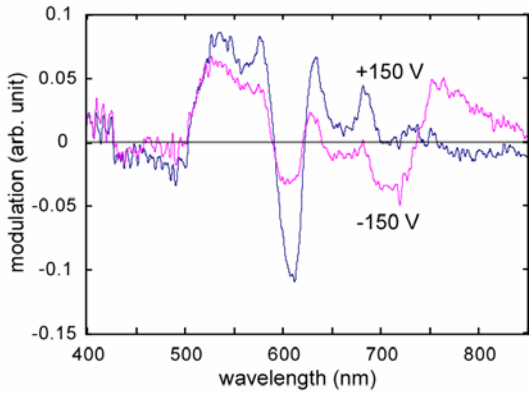

Figure 3 charge modulated microscopic reflectance spectrum obtained under the application of a negative and positive gate bias voltage (150 V).

For the negative bias application, signal modulation is clearly observed even at a low gate voltage region (not shown here) and is almost proportional to the voltage. On the other hand, signal modulation was not observed at a low positive gate voltage region. Such difference corresponds to the injection threshold of hole and electron. As mentioned, high threshold voltage of the electron injection was observed using the displacement current measurement (see Fig. 2). Interestingly, it should noted that the shape of modulation spectrum is different between hole and electron injection. This is presumably due to the spectrum difference between cationic and anionic states of the pentacene molecule. Such behavior suggest that the spectroscopic technique could be used to distinguish the injected carrier spacies (ex. holes and electrons).

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